

METHOD AND APPARATUS FOR EFFICIENT MESSAGING BETWEEN MEMORIES ACROSS A PCI BUS

5 Field of the Invention

The present invention relates generally to systems where memory of a central processing unit (CPU) in a multi-processing system may be accessed by another CPU. More specifically, the present invention relates to a multi-processing
10 system wherein the read operation over the shared bus is significantly slower than that of the write operation. A specific example of such a bus is that of the peripheral component interconnect (PCI) bus. Even more specifically, the invention relates to a system comprised of multiple packet processors in service aware networks (SANs), where wire-speed performance is essential to ensure a
15 high quality of network service.

Background of the Invention

20 In many multiprocessing systems, processors operate independently on various programs in order to execute the task at hand. Such systems are required when high performance is necessary, and cannot be achieved by the use of a single processing unit. Many such systems have been developed over time and multiple solutions exist for standard interface busses. The bus is used to
25 communicate between two separate systems, over an interface, which is jointly used by two or more processing units. As a matter of illustration, Figure 1 shows such a system. Each CPU (100) is generally comprised of a processor, and a local memory, used by that processor for its operation. In addition, it may include other input and output (IO) devices, however, such IO devices are not
30 relevant to the present invention. Each CPU (100) is connected to a standard

interface bus (110), whereby data is transferred between the CPU's of the system.

Interface bus (110) can be implemented as an available standard bus, or alternatively, as a proprietary bus. In the past, two common busses were used in personal computers (PC) and were also widely used in other computer systems. The two were known as the Industry Standard Architecture (ISA) and Extended ISA (EISA) busses. Other known standard busses are the Micro Channel and the Video Electronics Standard Association (VESA) busses. However, with the development of higher speed processor and peripheral devices, higher speed busses had to be developed, one of which is the Peripheral Component Interconnect (PCI) bus. In a PCI system, with the exception of certain refresh cycles, a write request has the highest priority, and therefore is handled earlier than any other request, including a read request. Therefore, a write is generally performed faster than a read. Moreover, a write operation is performed to a buffer, thereby releasing the CPU immediately to perform other operations. In contrast, a read operation does not release the CPU until the data is made available to the CPU. The time difference can become even more significant when a multiple layer PCI system is put in place. Even more important is the case where wire-speed operation is required for a SAN system, and using of read operations across the bus reduces the overall response time of the system.

Several patents disclose a variety of methods related to affecting the overall performance of PCI system, by attempting to address issue of the time imbalance between a read operation and a more time efficient write operation. Larson et al. disclose in US patent 5,524,235 an arbiter circuit to control access to main memory through a PCI bus. The disclosure describes how, under certain conditions, the processor-to-memory write requests are delayed to allow other cycles to proceed. Wade et al. disclose in US patent 5,613,075 a method by which a master on the bus can guarantee certain performance levels,

including for read operations. This allows the system to predict the worst-case situation of providing access to read operations, and this level can be fixed according to an arbitrary threshold level.

5 US Patent Nos. 5,634,073 and 5,634,073 to Collins et al., describe a more complex system where a controller handles a multiple queue system between the processor and the CPU. The system is also capable of checking if a write operation already exists into the same address into which a read request is made. They also propose various ways of improving the prediction of the rules
10 to be used to increase system efficiency.

US Patent No. 5,835,741 to Elkhoury et al., discloses a system that addresses the performance issues relating to a burst mode. The fast burst mode allows for efficient access by means of sequential accesses to sequential memory
15 addresses.

US Patent No. 5,754,802 to Okazawa et al., suggests a method and apparatus for increasing data transfer efficiency, specifically for preventing a deadlock situation, of a read operation in a non-split transaction bus environment by
20 substituting a write operation for the read operation. Basically this is done by substituting one of the write operations with a read operation to an IO device. The IO device then executes the write in the local environment.

A more complicated approach is described in US patent 6,134,619, which
25 however, requires specialized hardware for the indication of space availability in the queue, and a read operation on the PCI bus. This solution is tuned for the case of multiple processors using different operating systems. In US patent 6,145,061 Garcia et al propose a scheme for a circular queue with head and tail pointers, and certain ways to access the queue which further allow dynamic
30 allocation of the queue size.

Prior art does not address the need of multiple processors to access data over busses such as PCI, in a manner that (a) reduces significantly the overhead associated with the read cycles, and (b) allows a system, such as a SAN system
5 to operate at wire speed.

Summary of the Invention

10 It is an object of the present invention to describe an apparatus and a method for more efficiently moving data from one CPU to another over a PCI bus.

It is another object of the present invention to provide apparatus and methods for enhanced queue management.

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These objects, and others not specified hereinabove, are achieved by an exemplary embodiment of the present invention, wherein a shared bus is capable of performing write operations significantly faster than read operations. The invention discloses an implementation allowing the execution of an across a
20 computer bus read operation by its substitution with a write operation and a read to local memory. The invention is particularly well-suited for the case of the PCI bus. A method is disclosed for queue management providing enhanced performance.

25 In one exemplary embodiment, a computer system for transferring data between a receiving central processing unit (CPU) and a transmitting CPU by using only write operations, comprises: a receiving central processing unit (CPU); a transmitting CPU; a local memory for receiving CPU; a local memory for transmitting CPU; means for connecting between receiving CPU and second
30 CPU where such means transfer write operations faster than read operations;

and a circular queue defined between designated addresses in the local memory of the receiving CPU.

In an alternative embodiment, at least one receiving register for control of the queue is allocated in local memory of the receiving CPU and at least one transmitting register for control of the queue is allocated in the local memory of the transmitting CPU.

Brief Description of the Drawings

Figure 1 is a schematic diagram of multiple CPUs connected by a common bus, in accordance with an exemplary embodiment of the present invention;

Figure 2 is a diagram of the queue system between two CPUs, in accordance with an exemplary embodiment of the present invention;

Figure 3 is a flow chart of a write operation into a queue, in accordance with an exemplary embodiment of the present invention;

Figure 4 is a flow chart of the write operation into a queue with a tail, in accordance with an exemplary embodiment of the present invention;

Figure 5 is a queue diagram, before and after a write operation, illustrating use of the queue tail, in accordance with an exemplary embodiment of the present invention; and

Figure 6 is a flow chart of the read operation from a queue with a tail, in accordance with an exemplary embodiment of the present invention.

Detailed Description of the Invention

In the exemplary embodiments described hereinbelow and with reference to
5 the Figures, there is shown an apparatus and method which accomplishes the
transmission of a data message from a transmitting CPU to a receiving CPU
across a data bus, using a series of write operations and with no read operations
being performed across the said data bus.

10 With reference to Fig. 1, an exemplary embodiment of the present invention
comprises a system 10 containing at least two CPU's 100, inter-connected by a
PCI bus 110. Each CPU 100 has a memory portion that is accessible by at least
one other of the CPUs connected to PCI bus 110. The operation of the CPU's
are totally independent, and a CPU may use data provided by another CPU at a
15 rate that is not under the control of the CPU providing the data. More specifically
each CPU can write to any other CPU in the system. The present invention may
also be practiced for transfers between CPUs connected by a data bus other
than the PCI type used in the exemplary embodiment.

20 Figure 2 is a diagram of the queue system 20, in accordance with a
preferred embodiment of the present invention, between two CPUs that are
interconnected as shown and described in FIG. 1 hereinabove. While only one
transmitter 210 and one receiver 200 are shown connected through a PCI bus
25 250, a person skilled in the art can easily expand it into a system having a
plurality of transmitters and receivers. Both receiver 200 and transmitter 210 are
actually components of a CPU sub-system each unit of which includes a
processor, local memory, IO devices and other optional elements. Receiver 200
has a memory area that is defined as a cyclical queue 240. Generally such
30 queues have two pointers, one that points to the memory location where reads

are supposed to happen, and another pointer pointing to the next place for writing new information. As the queue has a limited available memory, once the write pointer reaches the upper limit of the queue, it resets and begins from the initial location of the queue. A similar procedure is used for the read pointer that follows the write pointer, at a different pace.

A cyclical queue is an area of memory used to store a continuous stream of data by starting again at the beginning of the queue after reaching the end. A cyclical queue may further be written by one process and read by another. Separate read and write registers are maintained. These are not allowed to pass each other otherwise either unread data would be overwritten or invalid data would be read.

It has hitherto been the case that when writing into a cyclical queue from the transmitter to the receiver, the transmitter side required the knowledge that there is space available in the queue to perform such a write. In order to perform such a function, a read request needed to be performed, thereby checking if such space is available. However, in systems where the read operation is relatively slow, such as in a PCI bus, an alternative solution is preferable and is disclosed hereinbelow in accordance with an exemplary embodiment of the present invention.

Referring again to Fig. 2, receiver 200 has a memory queue 240, a read head register 230 and a total read register 220. Read head register 230 contains the address of the next byte of data to be read in memory queue 240. Total read head register 220 contains the total number of bytes that have been read from queue 240. The receiver 200 is connected to a transmitter 210 through a PCI bus 250. Transmitter 210 comprises a total read register 260, a total write register 270 and a write head register 280. The queue length 245 and a copy of

the queue length **285** are kept on both receiver **200** and transmitter **210**, respectively, during system initialization.

In an exemplary implementation the processor's function is performed by
5 a packet processor. The memory queue **240** location is assigned in the memory
through allocation of a certain area, i.e., from a designated address to another
designated address. The content of read head register **230** is an address
pointing to the location from which data is to be read. When receiver **200** reads
data received from transmitter **210**, it uses the address indicated by read head
10 register **230** to access the data necessary, and move it to a portion of the local
memory for further use by the system, for example, by copying the data to a
register of the processing unit. That is, data can be rewritten to another part of
the memory which is not part of memory queue **240**, but which is not written
across PCI bus **250**.

In an alternative embodiment, data may just be read from the location, if
that read only needs to be done once during the data's existence at the site of
receiver **200**. For example, if the data is a telephone number that is needed to
be called as soon as it is read, and then is no longer needed, there is no need to
20 write the data.

As reads from memory queue **240** progress, the contents of read head
register **230** and total read register **220** are updated to account for the data that
was read. As writes progress, the contents of both total write register **270** and
25 write head register **280** are updated. Performing unsigned binary calculations
ensures that regardless of the actual length allocated for the memory queue **240**,
the pointers are correct, as long as certain conditions apply. The condition is
that in an N-bit address space, the length of the queue is not larger than 2^{N-1} .
For example, in a 32-bit address space, covering 4 gigabytes of memory, the

number of bytes allocated for memory queue **240** is not larger than 2 gigabytes, or 2^{31} . For all practical purposes this is an easily accommodated limitation.

The data in memory queue **240** is written in such a way that it contains a header separator, denoted in Fig. 2 as length and protocol ("LP"), and actual message content, marked as "mm". The last message of the last data is followed by a stopper designator separator, which is marked as "FM," wherein F represents a hexadecimal numerical value and M represents a predefined magic number. The "LP" contains at least a length field, designating the amount of data to be read in the following message. Usually this is a number of bytes to be read. It further contains a predefined identification number, also known as a "magic number", which is used by the system to verify correctness of the queue management. The use of the magic number is demonstrated herein below.

The last data chunk is followed by a stopper designator to ensure that the address in read head register **230** is not incremented beyond that point. If it is reached, the system discontinues reading until such time as additional data is written to memory queue **240** by transmitter **210**. When a data message is added, the "FM" field is replaced by an "LP" field. The "FM" is comprised at least of a stopper designator, which is a predefined numerical value, followed by the predefined magic number.

The initialization of such a system requires that total read register **220** and total write register **270** are initialized to the same arbitrary initial value. Both write head **280** and read head **230** should be set to the address in memory that is the first byte of memory queue **240**. Initially, the first bytes contain the "FM" message, indicating that no valid data is available. Both receiver queue length register **245** and transmitter queue length register **285** are initialized to contain the designated length of memory queue **240**. At this point, when receiver **200** attempts to read data from memory queue **240**, it reads the "FM" message, and

waits for new data to be written into memory queue 240 by transmitter 210. Meanwhile, transmitter 210 finds it possible to write into the memory queue 240 because when subtracting the content of total read register 260 from the content of total write register 270 it shows the value "0". Since queue length 245 is larger
5 than "0," transmitter 210 may write a message into memory queue 240.

With reference to FIG. 3, there is shown a write operation flow chart in accordance with an exemplary embodiment of the present invention. The first
10 step 300, prior to writing into memory queue 240, is to check that the length of the message is shorter than the total length allocated for the entire queue. The length of the message is provided from transmitter 210 when it receives a message to be transferred to receiver 200. If the length of the message is longer than the entire length allocated for memory queue 240, then an error
15 message is generated in step 310. Otherwise, the amount of memory available in memory queue 240, for writing a message, is compared against the length of the message. This is done by subtracting the difference between the content of total write register 270 and the content of total read register 260 from the queue length 285 of memory queue 240, and in step 320 comparing the result with the
20 length of the message. If there is not enough space in memory queue 240 to write the message, the transmitter 210 waits in step 330 until there is sufficient space. This happens as reads take place from the queue, and memory is freed for use. If there is enough space to write the message in memory queue 240, then the message is written in step 340 into memory queue 240 followed by the
25 "FM" to signal the end of the last valid message 350. Only then, the old "FM" is replaced, in step 360, by writing over it an "LP" message, to signal the end of the one-before-last message, is not a last message in the queue anymore.

In order to ensure that the system operates correctly, this last operation of
30 replacing "FM" with "LP" must happen as an atomic operation. This means that

the entire operation is performed in one transaction with no interruption, i.e., no other operation on the queue occurs until this operation is completed. Specifically, in a PCI bus, an atomic operation occurs only if the data written or read is aligned on a four byte address, i.e. any address that is divisible by four, such as 8, 12, 100 etc. Also, the write operation is limited to four bytes. In a PCI bus an atomic operation is always performed on four bytes that are aligned on a four byte address. Writing 24 bytes, for example, results in three separate operations that are not atomic. In certain cases the message may not be a multiple of four bytes, and therefore may require the message to be padded by one, two or three bytes in order to get it to be of a length that is a multiplier of four bytes. In addition both "LP" and "FM" should be four bytes in length. The result is that at all times the message, the "LP" and the "FM" are each aligned on a four byte address. The "LP" contains the original length of the message, prior to the padding.

A well-known method of splitting a message between the tail and head of a cyclical queue, would require that there is sufficient space for writing the data into the queue, however, the actual writing is performed by splitting the writes to the tail of the queue, then the head of the queue, and after that back to the tail of the queue to update the old "FM" to an "LP". While possible, this approach reduces the overall performance of the system and another approach, utilized by the present invention, is illustrated in the flow chart of Fig. 4.

With reference to Fig. 4, there is shown a flow chart illustrating a process of a write operation into a queue with a tail, in accordance with an exemplary embodiment of the present invention. For this purpose the concept of the maximum message is introduced. This is a limitation imposed on the length of the message that may be written into the queue in one write operation. When the queue is allocated in memory, an additional space, or a tail, which is the length of the maximum message, is added to the queue length. The write

process begins by checking **400** if the message length is larger than queue length **285**, or if the message is larger than the maximum length allowed **410**, an error message is generated **420**. If the message size is within the allowable length, then the available space in queue **240** is checked, based on data in the transmitter **210** and contained in its respective registers **430**. If there is not enough space, then transmitter **210** waits until such time as enough space is made available **440**. Once sufficient space is available, the message is written **450** into memory queue **240** and, if necessary, alignment bytes are added **460** to ensure that the message is aligned with the specific alignment restrictions of system **10**. In the case of a system **10** that incorporates a PCI bus **250**, such an alignment is a four byte, or 32 bit, alignment, hence one, two or three padding bytes will be added in order to achieve such alignment.

The "FM" message is now written **470** at the end of the message, and then the "FM" at the beginning of the message is replaced **475** by an "LP" message which must occur as an atomic operation as explained above. In step **480** it is determined whether the write operation has crossed the boundary of the queue length. If the queue boundary was crossed, i.e., the end of the message was written into the tail of the queue, an address, which is determined from the initial write head address, is added **485** to the queue length, then the write head register address must be updated as follows:

new write head = old write head + padded message length + 2 * stopper length – queue length.

Thus, there are two stopper lengths, in order to account for a stopper at the beginning and a stopper at the end.

This operation, in fact, brings the write head pointer to the same place that it would have been, had the split write operation been used, as described

above. The advantage is clear, as calculation complexity is reduced and performance increased, a performance advantage that is achieved at the expense of additional memory. With reference to Fig. 5, there is shown a schematic illustration of that operation.

Fig. 5 is a queue diagram, before and after a write operation, illustrating use of the queue tail, in accordance with an exemplary embodiment of the present invention. This example assumes that the write head is at address 1950, and the queue length is 1000, beginning at address 1000. If the maximum message allowed for the example is 100, then the address of the end of the tail of the queue is 2100. When a message of length 80 is written to the queue, it is written from address 1950 through address 2030. After the write operation, the write head is updated to address 1030, instead of the address 2030, as the 2030 address is within the tail area.

If the queue boundary is not crossed, then the write head register is updated as follows:

$$\text{new write head} = \text{old write head} + \text{padded message length} + 2 * \text{stopper length}.$$

Fig. 6 is a flow chart of the read operation by the transmitter 210, from a queue with a tail, in accordance with an exemplary embodiment of the present invention. When a read operation is requested by the local CPU of the receiver, the queue is checked 600. If the stopper indicates that it contains the "FM" designator, then the receiver 200 waits 610 until such time as the "FM" designator changes to "LP," indicating that the content of the queue, that follows, contains a message.

Once it is determined that the queue contains a message, the "magic" number is checked 630 for validity. The "LP" contains the length of the

message, excluding the length of the padding bytes. This information is used to actually read **640** the data from the memory queue **240**. Next, the length of the message, including the padding bytes, is calculated **650**, followed by a check **660** for crossing the boundary of the queue into the tail. If the boundary of the queue was crossed, then the new read head is calculated **670** as follows:

new read head = old read head + padded message length + 2 * stopper length – queue length.

However, if the boundary of the queue is not crossed, the new value for the read head is calculated **680** instead as follows:

new read head = old read head + padded message length + 2 * stopper length.

Essentially this method of calculating the new address is identical to that used by the write operation, however, the only exchange between the receiver **200** and the transmitter **210**, after initialization takes place, is the update by the receiver to the transmitter of the number of data bytes read that is only done through the use of write operations resulting in an overall performance advantage for the system.

The process described above is advantageous over prior art, as all the exchanges between the transmitter and the receiver are done through write operations. As on certain busses, such as PCI, the write operation is considerably faster than that of a read operation, the ability to use only write operations to transfer data from one unit to the other, provides for overall higher system performance. This is specifically important in service aware networks (SAN), where multiple packet processor may be operating over a PCI bus, and operation at wire-speed, is essential for the overall network performance. Wire

speed is the speed at which packets can flow through the network wires, without undue pause, for example, for network management administrative reasons.

It should be appreciated that the preferred embodiments described above
5 are cited by way of example, and that the present invention is not limited to what
has been particularly shown and described hereinabove. Rather, the scope of
the present invention includes both combinations and sub-combinations of the
various features described hereinabove, as well as variations and modifications
thereof which would occur to persons skilled in the art upon reading the
10 foregoing description, and which are not disclosed in the prior art.